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Socially optimal storage capacity with intermittent renewables

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Extended Abstract

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Abstract Summary

This paper develops a dynamic stochastic central planner model of optimal storage operation and capacity in an electricity system with intermittent wind and solar generation. Calibrated to German data, the model yields optimal storage operation under weather uncertainty in a welfare-based framework. Reintroducing a fossil fuel backup allows to quantify abatement costs for various levels of CO2 emissions.

Methodologically, the paper makes three main contributions: a joint continuous-time stochastic model of wind and solar supply with time-of-year variation and weather uncertainty; a utility specification that combines demand response with value-of-lost-load considerations around a calibrated reference demand level; and a certainty-equivalent LCOE measure that is consistent with welfare under uncertain consumption. These elements clarify a central mechanism: when no fossil fuel is burned, insuring the system against low-production periods requires either large storage energy capacities or extreme renewable capacity overbuilding, so that enough electricity is produced even in the worst moments. This point is illustrated by hydrogen storage in salt caverns: although hydrogen is often discounted because of round-trip losses and conversion requirements, its low energy-capacity cost can dominate those losses when compared to batteries.

Quantitative results suggest that an energy mix consisting of wind and solar power as well as hydrogen storage in salt caverns could achieve an LCOE of 60-110 EUR/MWh (depending on the discount rate), with roughly three times the wind and solar capacities installed when compared to 2025 and around 30-40 TWh of storage energy capacity. A comparison with a perfect foresight approach based purely on past observed capacity factors highlights the important role of uncertainty for the optimal storage energy capacity. Decentralizing the central planner solution could prove difficult if investors are risk-averse: simulated average revenues over periods as long as 15 years show a considerable variance depending on the various realizations of renewable production.